

xEV Battery Technology Requirements and Advances

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January 2015

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Presentation Outline

- ❖ **Hybrid-Vehicle Technology and Market Trends**
- ❖ Energy-Storage Solutions for
 - High-Voltage HEVs
 - Low-Voltage Systems
 - PHEVs
 - EVs
 - Li-Ion xEV Battery Matrix
- ❖ xEV Battery Market

Powertrain Electrification

Tank to Wheel fuel consumption / CO₂ Emission Reduction*

3-5%

10-15%

25-40%

40-70%

100%

Micro Hybrid

Mild Hybrid

Full Hybrid

Plug-in
Hybrid

Battery Electric
Vehicle

Well to Wheel fuel consumption / CO₂ Emission Reduction

3-5%

10-15%

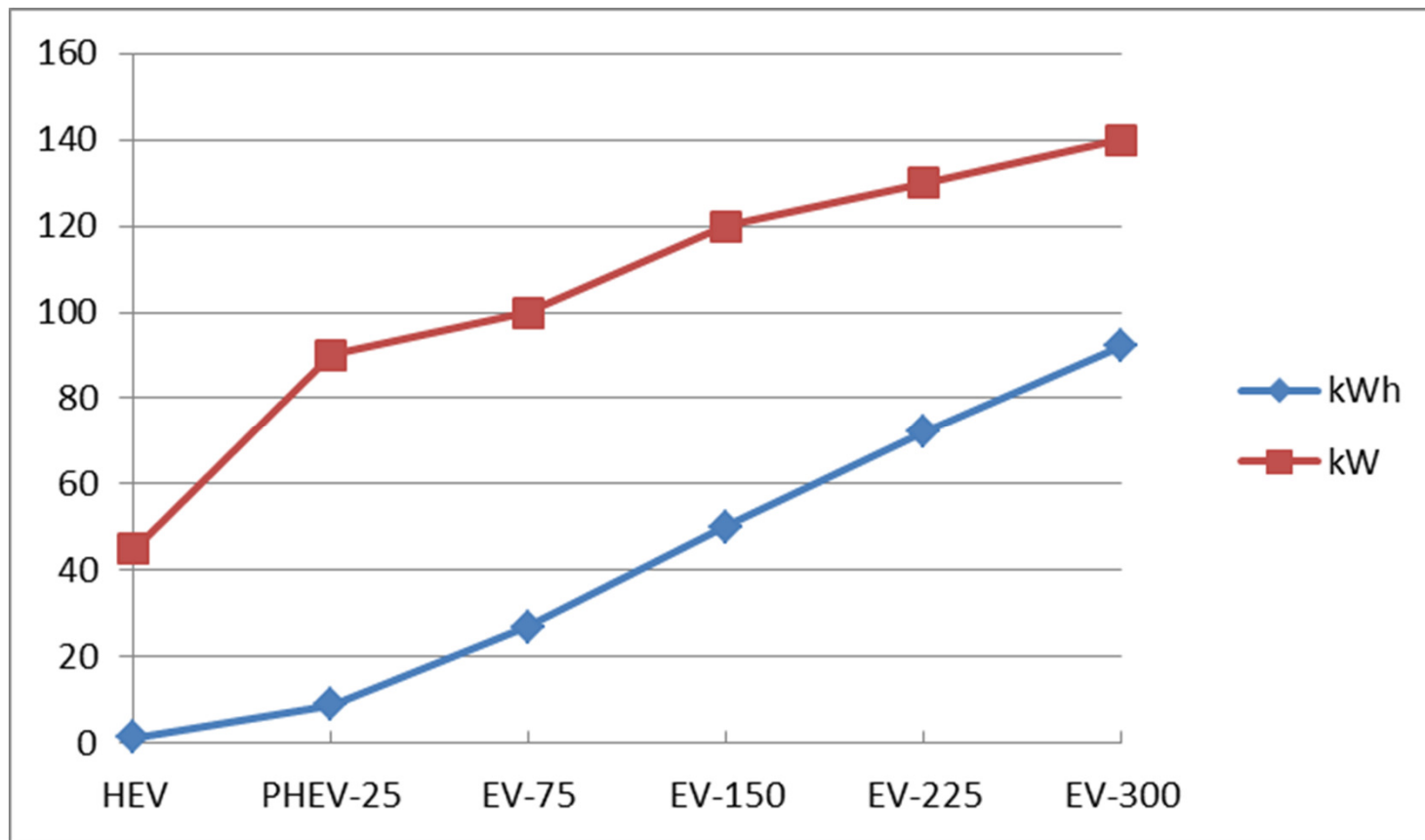
25-40%

30-70%

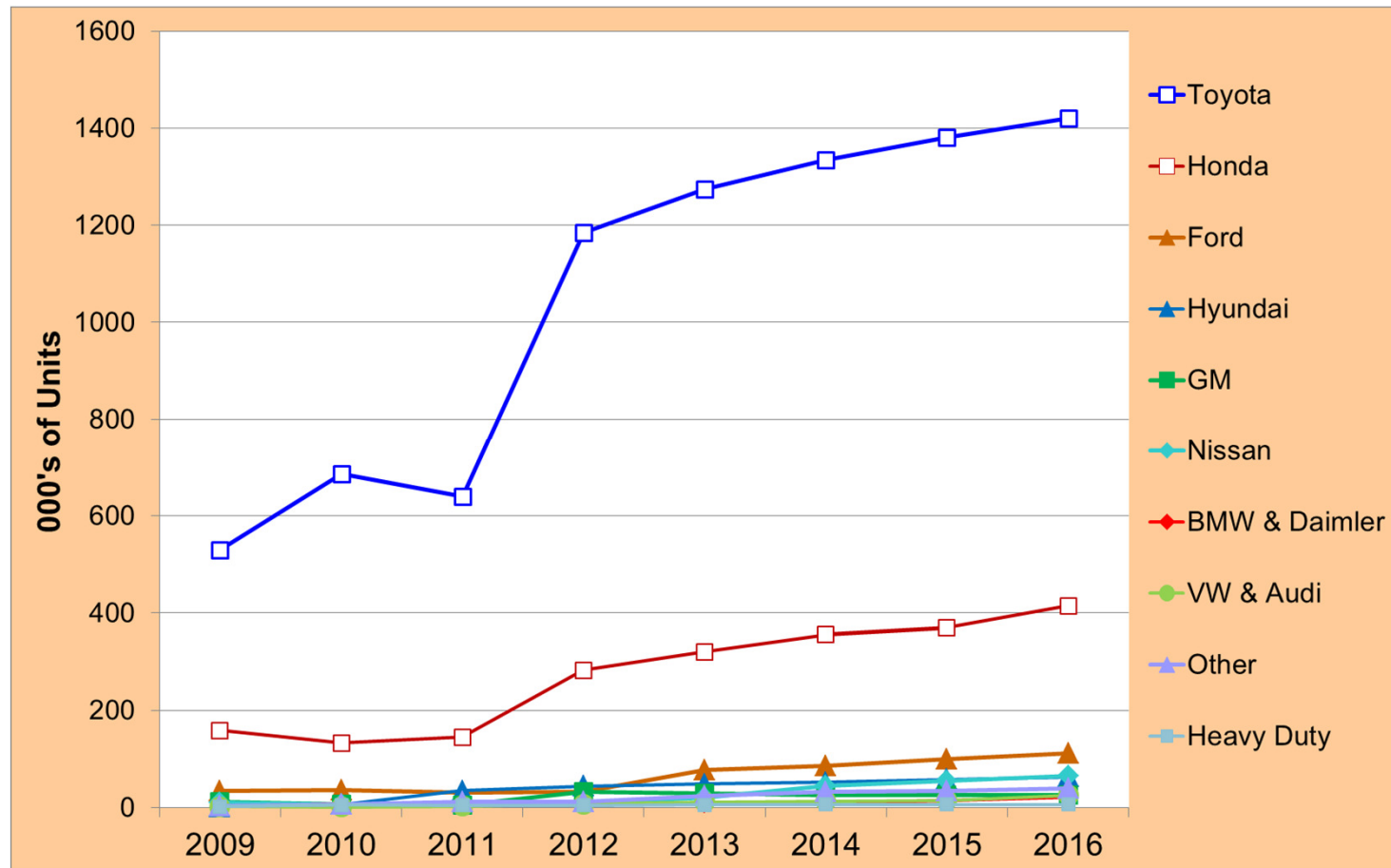
30-100%

Increasing Cost

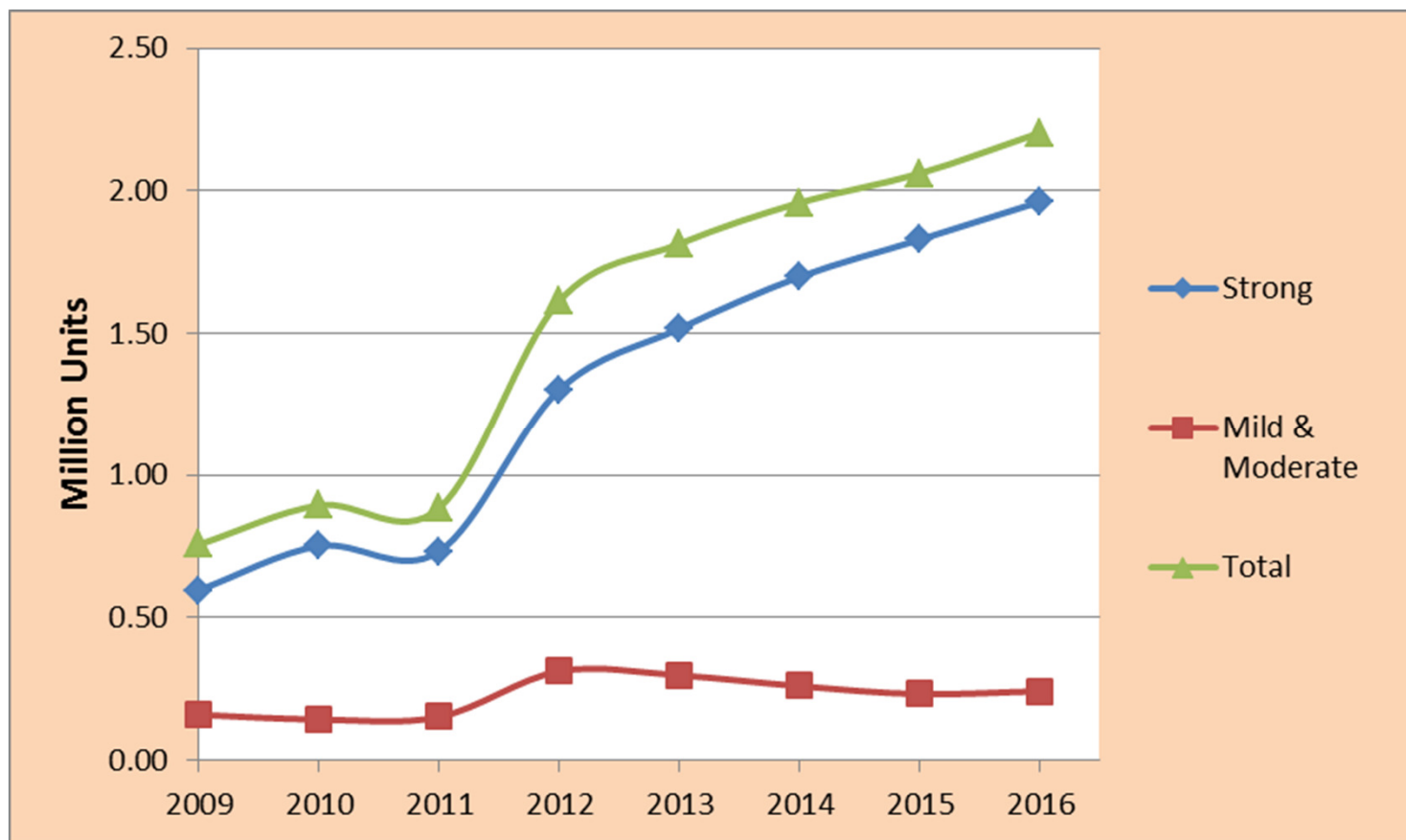
xEV Battery Power and Energy vs. Application



HEV Market by Vehicle Producer 2009 – 2016



HEV Market by Hybrid Category





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➤ The main opportunities are in:

- Improving low-temperature power and reducing power fade to bring the level of oversize down **to reduce cost**
- Improving power and DOD range **to reduce size and cost**
- Simplifying electronics and cooling **to reduce cost**
- Proving life and reliability same or superior to those of NiMH, **to reduce risk and warranty cost**

- At least 4 configurations with varied energy-storage requirements
 - Micro 1 and 2 at 14V nominal
 - Mild 1 and 2 at 48V nominal
- Most solutions for micro 2 and mild systems consist of two energy-storage devices
 - Balance of loads
- Design driver varies by application and solution
 - Low-temperature power
 - Charge acceptance
 - Voltage compatibility
 - Cyclability
 - High-temperature tolerance
- Cost of pack beyond cells and power electronics is a major challenge



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***Seven years into the current wave of development,
there are still major cell design variations...***

- **Cell packaging**
 - Metal can versus pouch
- **Cathode Chemistry**
 - NMC, LFP, NMC+LMO blend
- **Cell assembly**
 - Stacked, spirally wound, or semi-wound?
- **Power level kW/kWh**
 - Depends on vehicle power/range ratio

PHEV Cells on the Market 2014

Cell Maker	Chemistry	Vehicle	Capacity	Configuration	Voltage	Weight	Spec Ener
	Cathode		Ah		V	Kg	Wh/kg
LG	LMO-NMC	Volt	15	Pouch	3.7	0.39	142
Panasonic	NMC	Prius	22	Prismatic	3.68	0.73	112
Panasonic	NMC	C-Max	25	Prismatic	3.68	0.75	123
Samsung	NMC-LMO	Porches	25	Prismatic	3.7	0.721	128
LEJ	LMO-NMC	Outlander	40	Prismatic	3.7	1.35	110
LEJ	LFP	Daimler	21	prismatic	3.3	0.64	108

PHEV Battery Technology Roadmap

- The key matrix is increasing usable energy density while reducing cost per unit of usable energy, without sacrificing safety and life
- NMC and LFP graphite chemistry promise to deliver 4,000+ cycles at 70-75% SOC swing
- Producers are aiming to raise specific energy at the cell level (for NMC) from 125 to 160+ Wh/kg with no sacrifice in safety or life
- \$200/kWh by 2020 cell level is being discussed

Current EV Cells

	Cell Maker	Chemistry	Capacity	Configuration	Voltage	Weight	Volume	Ener dens	Spec Ener	Used in:	
		Anode/Cathode	Ah		V	Kg	liter	Wh/liter	Wh/kg	Company	Model
1	AESC	G/LMO-NCA	33	Pouch	3.75	0.80	0.40	309	155	Nissan	Leaf
2	LG Chem	G/NMC-LMO	36	Pouch	3.75	0.86	0.49	275	157	Renault	Zoe
3	Li-Tec	G/NMC	52	Pouch	3.65	1.25	0.60	316	152	Daimler	Smart
4	Li Energy Japan	G/LMO-NMC	50	Prismatic	3.7	1.70	0.85	218	109	Mitsubishi	i-MEV
5	Samsung	G/NMC-LMO	64	Prismatic	3.7	1.80	0.97	243	132	Fiat	500
6	Lishen Tianjin	G-LFP	16	Prismatic	3.25	0.45	0.23	226	116	Coda	EV
7	Toshiba	LTO-NMC	20	Prismatic	2.3	0.52	0.23	200	89	Honda	Fit
8	Panasonic	G/NCA	3.1	Cylindrical	3.6	0.045	0.018	630	248	Tesla	Model S

EV Battery Technology Roadmap

- For a 20-25 kWh battery, the targets are 180Wh/kg and \$250/kWh (pack level) for 2020, but life and safety are to be confirmed for more aggressive designs
- For larger packs, lower power level and cycle life requirements make achieving above targets more likely
- Even higher specific energy will require higher-voltage, higher-capacity cathodes, and some silicon in the anode; this proposition is for after 2020
- Carmakers should not include Li Air or Li Sulfur in their 12-year plan

EV & PHEV Battery Technology Roadmap

COST

- \$ per kWh for EV and PHEV cells versus calendar life and production volume.
- Realistic pricing versus future pricing/buy in
- Cell % in EV and PHEV packs
- Will lower Power/energy cell be much more economical, will that justify going to larger range
- Material cell or pack making in China?

Safety

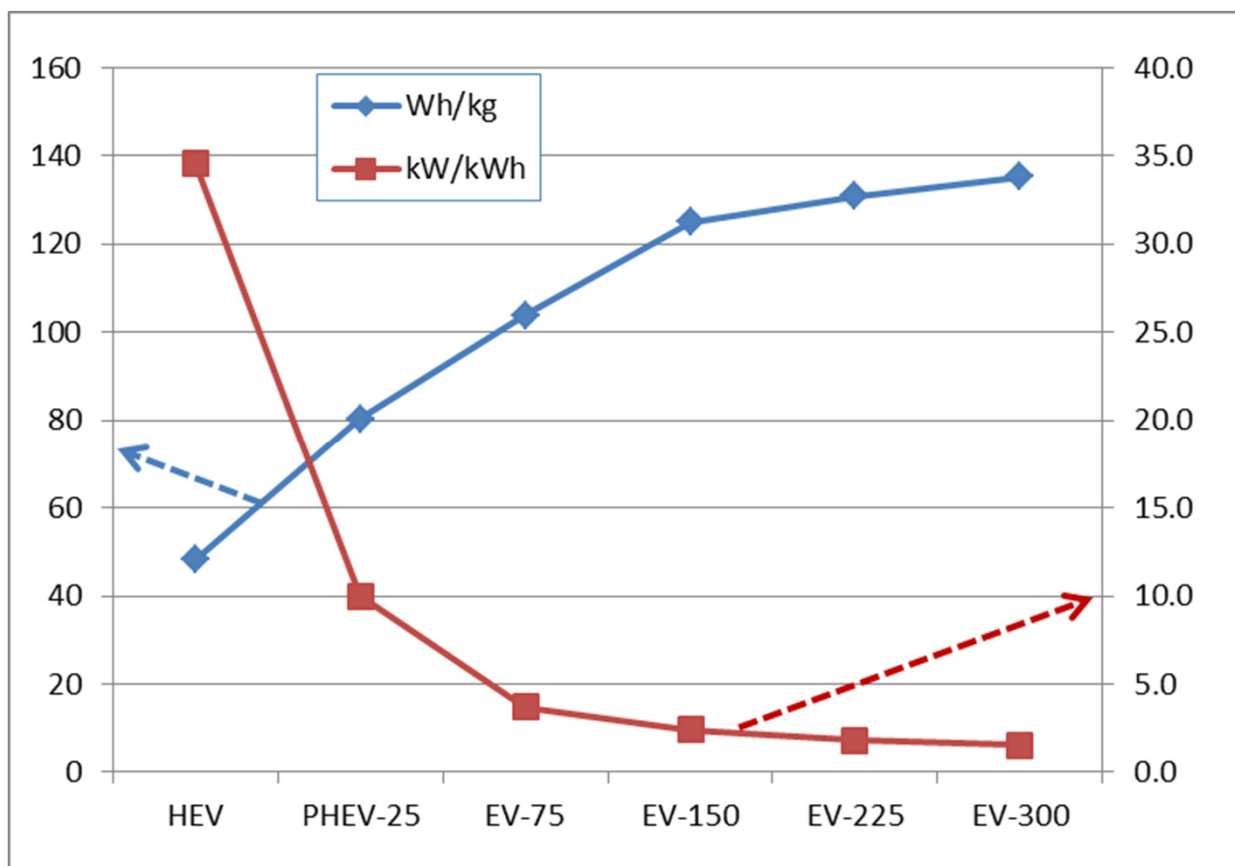
- Is abuse tolerance at the cell level absolutely necessary?
- Avoiding fire propagation
- What is the right internal short-circuit test?
- What is realistic crush protection?
- What level of overcharge at cell level?
- Influence of max cell voltage?
- Influence of cooling and temperature control?



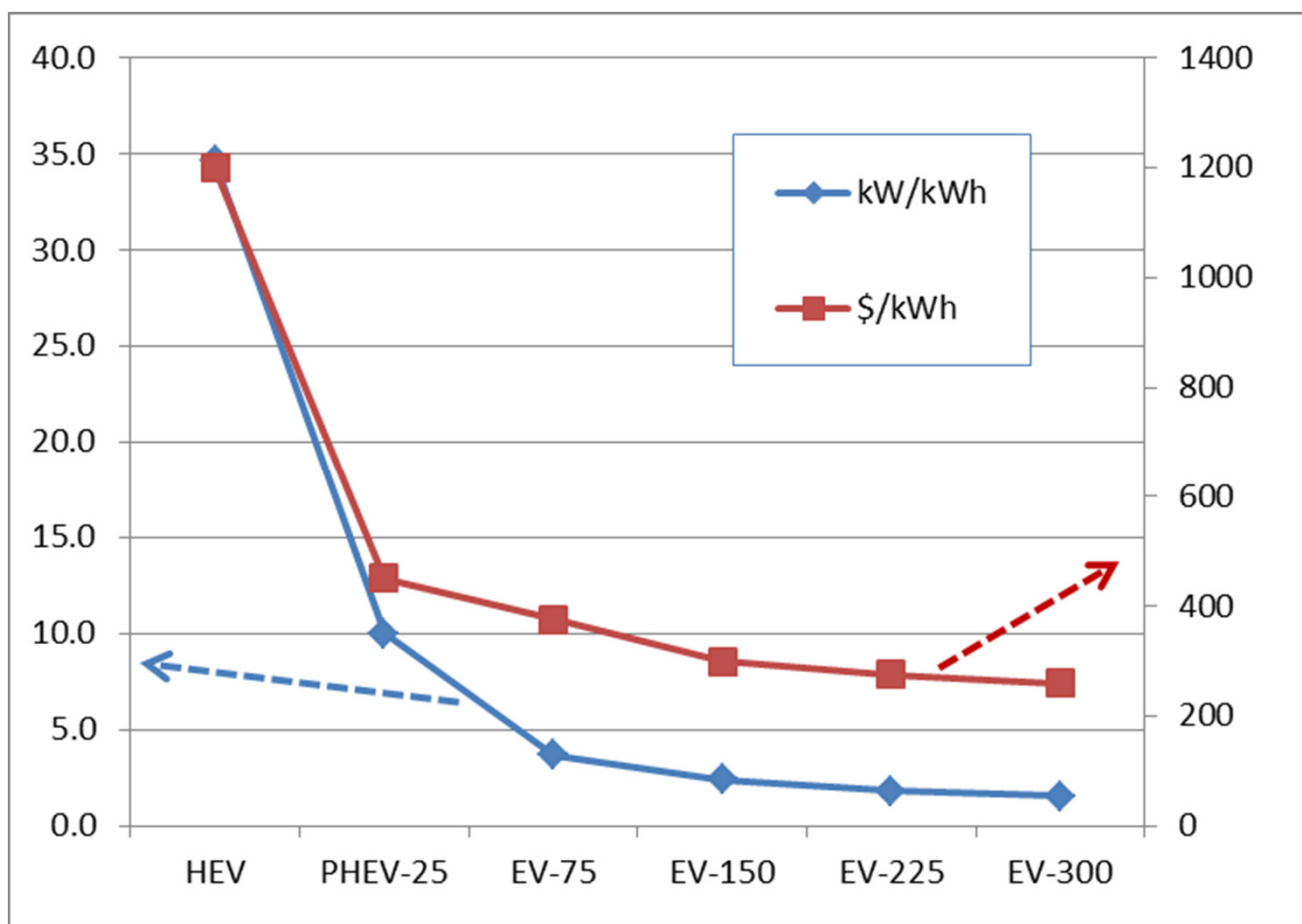
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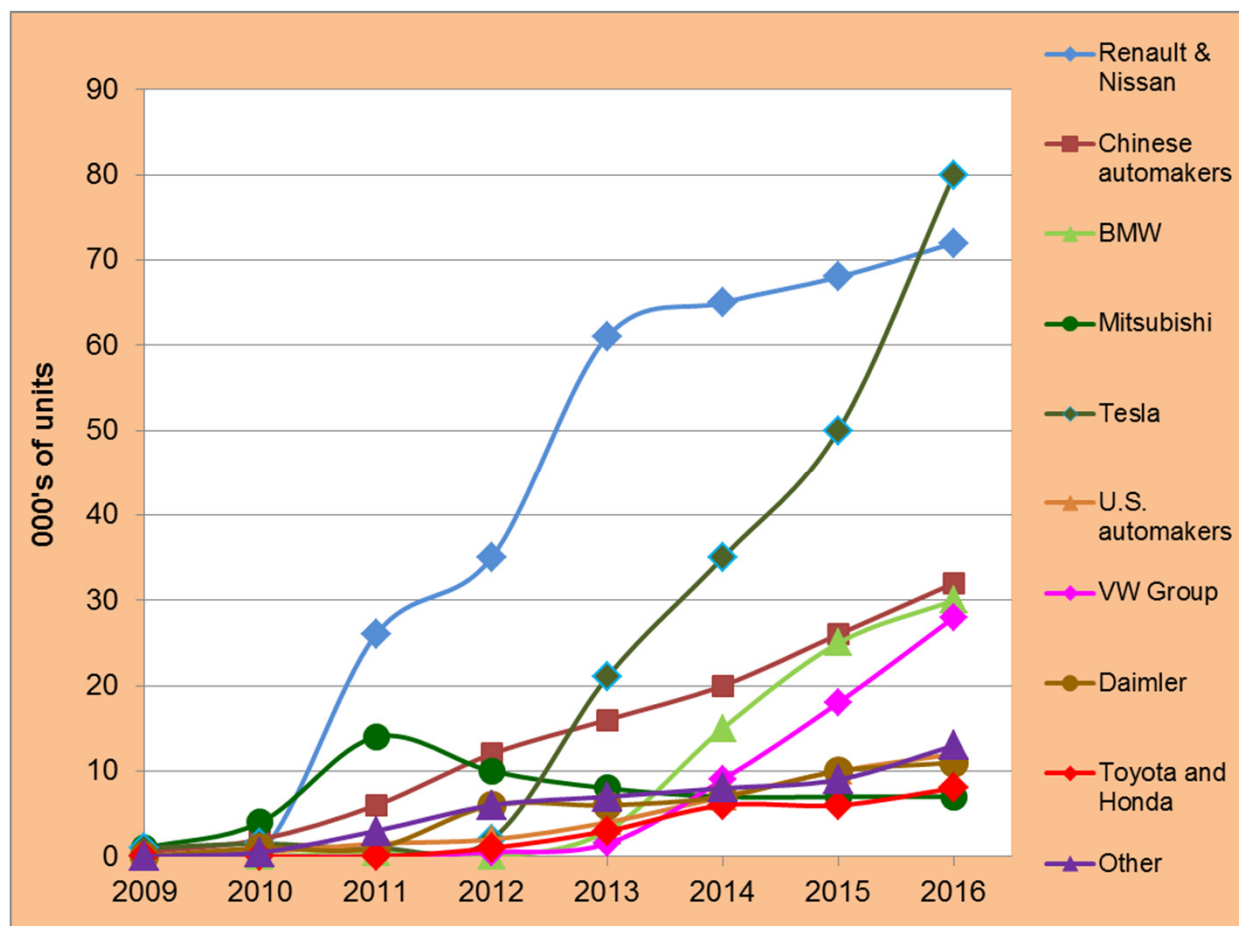
xEV Energy Density vs. Power Level



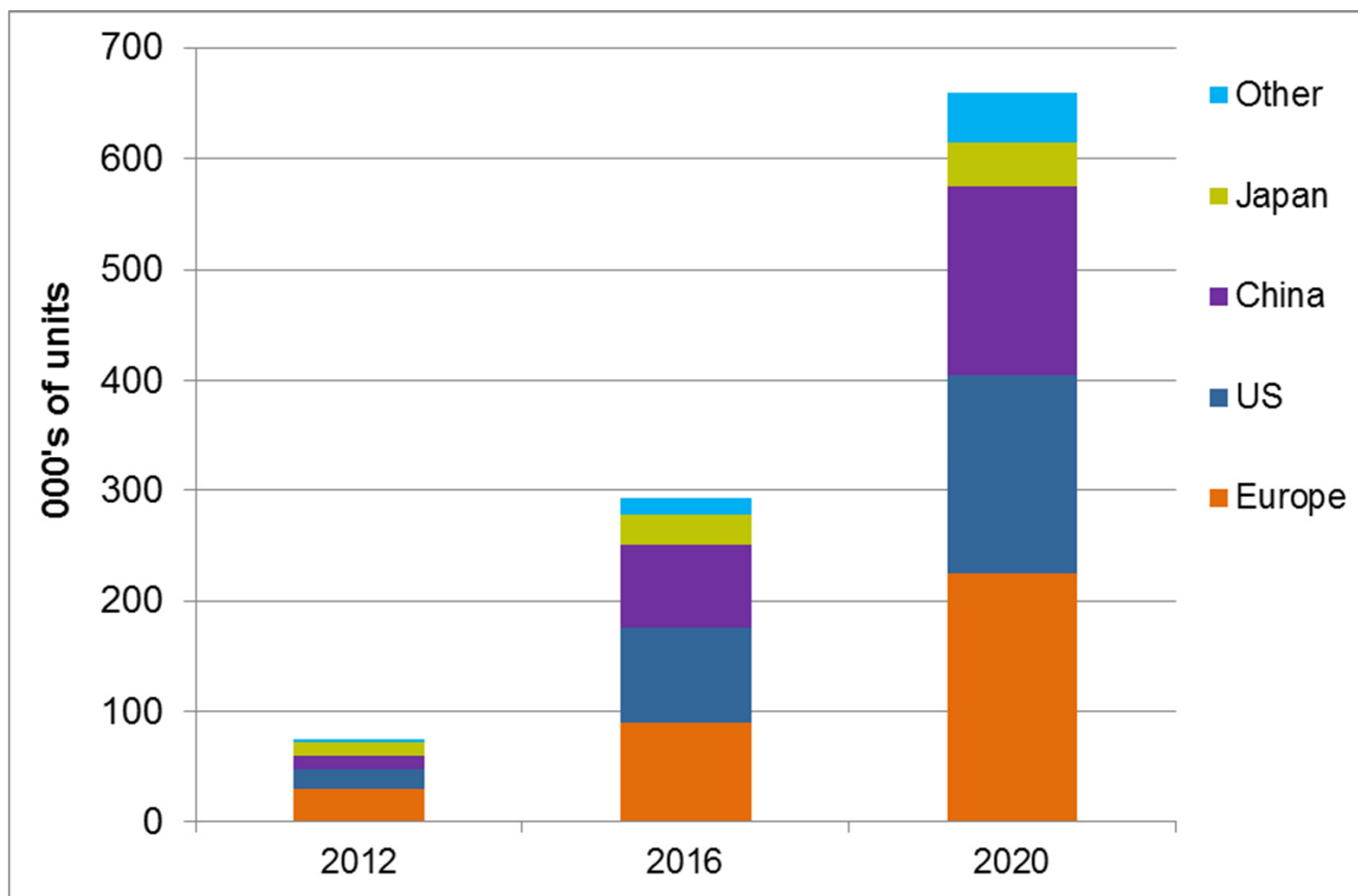
xEV Battery Cost vs. Power Level



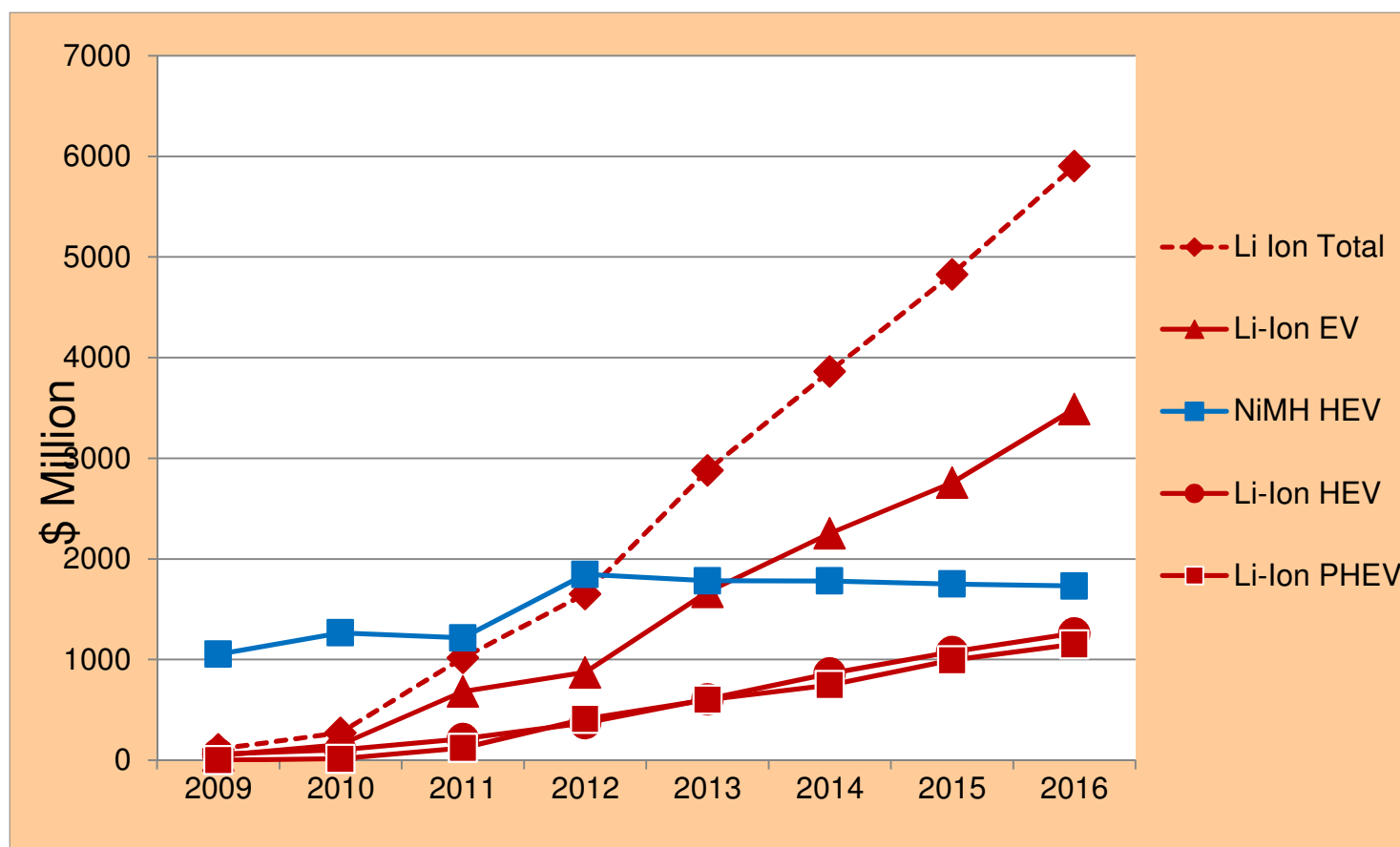
EV Market Forecast by Producer



EV Market Forecast by World Region

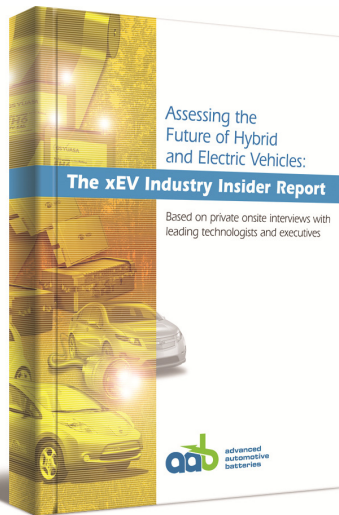


Combined xEV Battery Pack Business *(excluding micro hybrids)*



- Lithium Ion is the preferred energy-storage solution for most xEV architectures
- For the high-voltage systems, there is no competition in sight inside the next 10-12 years
- Design driver varies between applications
 - For high-voltage HEVs, reducing power fade and increasing power at low temperature
 - For low-voltage HEVs, improving charge acceptance and low temperature power and reducing pack-related complexity/cost
 - For PHEVs, increasing usable energy over 10 years of life
 - For EVs, improving energy density and calendar life at full SOC
- **To reduce the cost of materials, cell, and pack is the common design matrix for all applications**

☐ ***The x-EV Industry Insider Report*** *Assessing the Future of Hybrid and Electric Vehicles*



KEY TOPICS

- HEV market direction
- Future technology and market positions of automotive Pb-Acid and NiMH batteries and ultracapacitors
- **Performance, cost, durability, and safety factors for automotive Li-Ion batteries**
- Vehicle- and battery-market projections

2015 edition available in April

☐ ***The Tesla Battery Report*** *Available now*



advanced automotive & industrial/stationary battery conference

June 15 - 19, 2015

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signature sponsor

TOYOTA

host sponsor



NEW THIS YEAR!

- **AISTAM**, a new symposium on the emerging market for advanced batteries in utility, telecom, and industrial applications
- **LLIBTA tracks will feature unique sessions:**
 - Battery R&D program managers from government agencies and national labs provide overviews of R&D in their agencies
 - Poster +8 sessions with short presentations on key topics by principal investigators
- **Six specialized battery engineering areas** will be included in the Li-Ion engineering track
- **Exhibit+8** option offering exhibitors an opportunity to introduce relevant technical products
- **Poster+8** session: an 8-minute presentation slot for selected poster presenters
- **OEM battery pavilion** in the exhibit hall with mockups of the latest xEVs' batteries